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(54) Electrode pattern intended for tuning fork-controlled gyro.

(57) The invention relates to an electrode pattern arranged on the freely vibrateable legs on a tuning fork-controlled gyro. The electrode pattern comprises drive electrodes for generating a vibration in the legs of the tuning fork and sensing electrodes for sensing vibrations which occur in the legs. The sensing electrodes comprise a first electrode configuration (sensor electrodes) for sensing vibrations either out of the plane (24, 25, 26, 27) or in the plane (7, 8, 9, 10, 11, 12) of the tuning fork and a second electrode configuration (feed back electrodes) for sensing vibrations in the plane (34, 35, 41, 42) or out of the plane, (9, 10, 11, 12) of the tuning fork, for controlling the driving of the tuning fork in the plane or out of the plane, respectively.

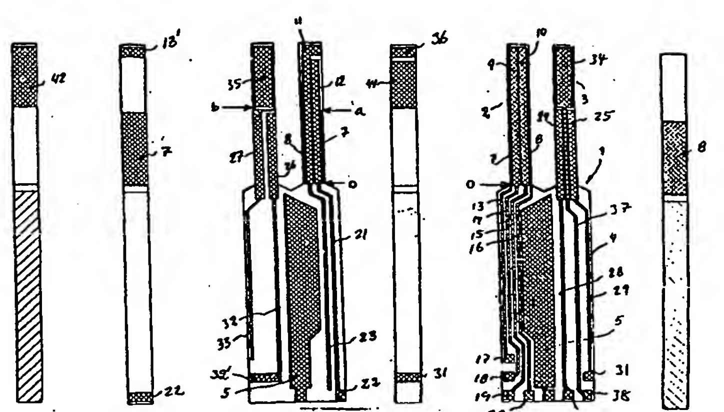

Fig 1e Fig 1d Fig 1b Fig 1f Fig 1a Fig 1c

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TECHNICAL FIELD

The present invention relates to an electrode pattern for a tuning fork-controlled gyro constructed of a piezoelectric material, preferably quartz, according to the preamble of Patent Claim 1 following.

PRIOR ART

It is already known to utilise vibrating masses as sensor elements for the gyros. These masses have most recently been constructed from quartz, which simplifies driving and sensing since quartz is piezoelectric. This also increases the possibility for constructing a robust gyro with high G numbers since the sensor can be made small. An example of such a sensor element is described in SE 89 00 666-2.

The base of this sensor element is firmly clamped, whereas the legs of the tuning fork can freely vibrate in two planes which are at right angles with respect to one another.

A mechanical vibration is generated piezoelectrically in one plane by means of drive electrodes. Vibrations are also produced, in a plane which is at right angles to the plane in which the drive electrodes generate vibration, through Coriolis forces which act on the sensor element when it is subjected to rotation around its longitudinal axis. These vibrations produced can be piezoelectrically sensed by means of sensor electrodes.

The legs of the sensor element have a transition part in connection to its base and an attachment part, which parts are rigid and do not participate in the vibration in any significant way. The drive and sensor electrodes cover significant parts of the vibrateable ends of the legs, and since the entire sensor element is integrally constructed of a piezoelectric material, for example quartz, all the material in the legs apart from the rigid transition part and mounting part will participate in the buildup of the respective sensing of the vibrations. This provides a gyro which withstands heavy environmental stresses, especially high acceleration stresses, and which has a small external volume. Due to weak currents and relatively high interference levels, however, it has been difficult to meet the necessary requirements for drift and zero signal.

Due to imperfections in production, there will always be a certain mechanical coupling between the two directions of vibration. This leads to an output signal being present from the sensor electrodes even if the sensor is not subjected to any rotation. Such "crosstalk" is unwanted since it worsens the performance of the gyro. One way of eliminating this coupling between the two directions of vibration is described in the above-mentioned SE 89 00 666-2, namely to balance one of the legs in such a manner that the legs have identical vibration characteristics. This balancing can be done by attaching or removing a mass from suitably selected places on the legs. Even if balancing the masses of the legs is necessary for other reasons, it is desirable to be able to adjust the characteristics of the sensor element in another way since an adjustment of the characteristics of the sensor element by means of such masses is troublesome and increases the costs of sensor element production.

In the sensor element described in SE 89 00 666-2, both legs are utilised both for driving and sensing which implies that the two electrode sets must share the space on the legs. The electrodes must be optimised for the available space, and the sensor electrodes are preferably placed close to the transition between base and leg, whilst the drive electrodes are placed further out on the legs.

Such a placement of the electrodes presents problems, however, due to the fact that the weak currents which are generated on sensing can easily be affected via stray capacitances due to the high electrical voltages of the driving. It has therefore been difficult to achieve the desired drift and zero signal requirements with the type of electrode configurations described in the abovementioned patent.

DESCRIPTION OF THE INVENTION

TECHNICAL PROBLEM

There is a requirement for small inexpensive gyros which have a high G number. The disadvantages with small dimensions in a quartz sensor are, however, that very small output signals are obtained which are easily disturbed by external factors.

As the accuracy requirements increase relating to drift and zero signal, effects such as stray capacitances and unevenly etched geometry will acquire an increased negative significance. The capacitance arising between the drive electrodes, Co, also entails a drift (caused by, for example, temperature variations) since it frequently cannot be completely compensated.

SOLUTION

The main aim of the present invention is to propose an electrode configuration for a quartz gyro with vibrating legs which provides the possibility of a solution to the problems stated above. The solution thus provides an improvement of the sensor presented in "J. Söderkvist, Design of a

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solid-state gyroscopic sensor made of quartz, Sensors and Actuators, A21 (1990) 293-296". The main characterising feature of the novel arrangement is apparent from the characterising clause in Patent Claim 1 following.

The novel sensor element is preferably constructed as a tuning fork in quartz crystal. The base of the tuning fork is firmly clamped whilst the legs of the tuning fork are allowed to vibrate freely. According to the invention, both legs of the tuning fork are galvanically insulated, which involves separated electrode configurations for driving (high voltages) and sensing (low currents). The drive electrodes are constructed in such a manner that vibrations can be generated both in and out of the plane.

The sensing electrodes are divided up into feedback and sensor electrodes, the feedback electrodes registering vibration in a drive unit which can consist of vibration in the plane of the tuning fork, and the sensor electrodes register vibration at right angles to the drive vibration, which can be the gyro signal. The feedback electrodes are used for minimising the effect of Co on the drive electronics, for permitting a constant mechanical drive amplitude, for counteracting temperature and ageing in certain material parameters and for analysing a useful sensor signal. Leads can be connected to the base of the crystal, for example with the aid of bonding or TAB, and by this means contact can be made with the surrounding electronics.

An electrode pattern proposed at present which has the features significant for the invention will be described below, at the same time referring to attached drawings in which Figure 1 shows the electrode pattern of the tuning fork seen from different directions, Figure 2 shows the field pattern in the piezoelectric material in a cross-section for electrode configurations used, and Figure 3 shows a block diagram of the electronics section.

Figure 1 shows an example of the design of an electrode pattern in a sensor element 1 in the form of a tuning fork-controlled gyro. Figure 1a shows the front of the tuning fork with two legs 2, 3 and a base part 4. The cross-sectional area of the legs is constant in this case along the entire length of the legs, which is not a functional requirement. The whole sensor element is produced from a single piezoelectric piece.

The legs of the sensor element are covered with drive electrodes for exciting a vibration of the legs, and sensing electrodes for sensing vibrations which occur both in and out of the plane. On the base 4 of the sensor element there are output pads/contact material for permitting connection of leads for contact with the surrounding electronics. The leads can be connected with the aid of wire-bonding, TAB (Tape Automated Bonding) or the like. The electrodes, the leads which connect the electrodes to the output pads and the output pads themselves can be applied by means of known technology from quartz production.

Both legs of the tuning fork are galvanically insulated, which involves separated electrode configurations for driving and sensing. The drive electrodes thus cover the left leg 2 in Figure 1a, whilst the sensing electrodes cover the right leg 3. For this to be possible, it is necessary that the base 4 participates in such a manner that the two legs are mechanically coupled to one another. The leads to the electrodes on the base part 4 are also divided into a drive side and a sensing side. Leads with high voltages (the drive side) can then be more easily kept apart from leads with weak currents, which reduces disturbances from stray capacitances. To further reduce disturbances between the drive side and the sensing side, an earth plane 5 is applied between the leads and at the same time leads with high voltages are placed as dipoles.

The left leg 2 is provided with six separate electrodes 7-12 arranged all around the sides of the leg, which can be seen in Figures 1a-1d. The electrodes 7 and 8 do not take up the entire length of the leg but extend from the base, marked by 0 in Figures 1a and 1b, to a distance a, where a is located in the range 30-60% of the length of the leg. This can be seen best in Figures 1c and 1d.

The electrodes on the front and back of the leg, that is to say the electrodes 9, 10 and, respectively, 11, 12 are divided into two and extend along the whole length of the leg.

The drive electrodes 7-12 on that part which is closest to the base of the leg, that is to say 0-a, form a first electrode configuration which generates a vibration of the legs in the plane of the tuning fork.

The part which is furthest out on the electrodes 9, 10 and, respectively, 11, 12 divided into two, that is to say in the area a-100%, forms a second electrode configuration which can be used for cancelling an unwanted vibration out of the plane. If it is not desired to cancel unwanted vibrations, the electrodes 9 and 10 and, respectively, 11 and 12 can be connected to form one electrode. The area close to the tip of the leg will then have only a function on balancing (fixing surface for applied or removed balancing material). The figures show how the electrodes 9 and 11 are connected to one another via a tongue 13', see Figure 1d.

The drive electrodes are connected by means of conductors 13, 14, 15, 16 to four output pads 17, 18, 19, 20 for connection to external drive electronics, see Figure 1a and 2.

The electrode 12 at the back is connected by means of a conductor 21 via a transition 22 to an output pad 19, whilst the electrode 11, for reasons

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of symmetry, has a dummy conductor 23 which extends along the base part 4.

There are two electrode configurations on the sensor leg, partly a first electrode configuration consisting of electrodes 24, 25, 26, 27 for feeding vibrations out of the plane, for example the gyro signal. The electrodes 24 and 27 are connected to one another over side parts via the electrode 42 which can be seen in Figure 1e. The electrodes are connected at the front by means of conductors 28, 29 to output pads 30, 31 for connection to the sensor electronics. The connection 30 thus suitably has zero potential. In order to resemble the front, the electrodes 26, 27 at the back have conductors 32, 33, the conductor 33 being a dummy conductor, whilst the conductor 32 is connected to the output pad 31 via a transition 32'.

The first electrode configuration 24, 25, 26, 27 is placed on the part of the sensor leg 3 which is closest to the base, preferably at a distance b where b is located in the range 30-60% of the length of the leg. The sensor electrodes also extend a short way on the base part 4.

The sensor leg also comprises a second electrode configuration for feeding vibrations into the plane (drive vibrations) consisting of four electrodes 34, 35, 41, 42 placed on the external part of the leg, that is to say in the area b-100%. The electrodes 34 and 35 are connected to one another by means of a tongue 36, see Figure 1f. The electrode 34 is connected by means of a conductor 37 to an output pad 38 for external electronics (for example the feedback signal).

Figure 2 shows an example of the appearance of the electrical field pattern in a cross-section of the two legs of a tuning fork-controlled gyro. Since the theory of the piezoelectric effect in such a gyro is already known per se, see

Jan Söderkvist, "A mathematical analysis of flexural vibrations of piezoelectric beams with applications to angular rate sensors" Acta Universitatis Uppsaliensis, 244, Uppsala 1990,

the piezoelectric phenomenon will not be described in greater detail here. Figure 2 is only intended to illustrate the appearance of the field pattern with an electrode configuration according to the invention. For that used in the subject matter, it is obvious that other electrode configurations can also be utilised, for example that the electrodes 24-27 can also be extended on the sides of the legs.

Figure 2a shows an example of the field pattern which occurs in the piezoelectric material in the drive leg 2 when an electrical drive voltage V+V− is applied to the drive electrodes 7-12. This field generates in this case an elongation in one part of the leg and a contraction in its other part as shown in Figure 2b, which causes the leg to want to bend in the plane.

Figures 2c and 2d show a corresponding field pattern which occurs in the sensor leg 3, where the sensing electrodes 24, 25, 26 and 27 have been marked. These electrodes are utilised for sensing vibrations out of the plane of the tuning fork.

When vibration is present, the piezoelectric crystal structure will be deformed, which leads to surface and volume loads being generated. These loads, together with the electrodes, will form field patterns like those in Figure 2a. These field patterns cause electrons to move to and from the electrodes, and a sensor current is created in this manner.

Figure 3 shows a basic diagram of the surrounding electronics section. The drive electrodes are connected to suitable drive electronics comprising a drive stage 43, which connection generates a sinusoidal electric feed voltage for the drive electrodes.

The sensor electrodes sense a vibration at right angles to the drive vibration, among others the gyro signal, and emit a sensor signal which is supplied via the signal processing element 44, comprising known circuits such as input stage and high-pass filter, to a demodulator 45 and low-pass filter 46. The output signal from the low-pass filter represents the gyro signal.

According to the invention, the sensing electrodes also comprise a second electrode configuration, feedback electrodes, which register vibration in a drive unit and emit a feedback signal which is supplied to corresponding signal processing elements 47. The feedback signal is supplied to the demodulator 45 of the sensor section so that the phase information of the sensor signal can be fully utilised. The demodulator 48 measures the sensor current which is in phase with the feedback signal. This unwanted signal can be cancelled via the electrodes 9-12.

It is to be considered as obvious that the drive vibration does not necessarily need to occur in the plane of the tuning fork. It can just as well occur out of the plane and the sensor vibration then consists of vibration in the plane. If these vibration directions are utilised, the function of the electrodes 24-27 should be exchanged for the function of the electrodes 7-12 and, respectively, 34-35, 41-42 should be exchanged for 9-12 in the above text.

Claims

1. Electrode pattern intended for a tuning fork-controlled gyro and arranged on the freely vibrateable legs of the gyro comprising drive electrodes for generating a vibration in the legs of the tuning fork and sensing electrodes for sensing vibrations which occur in the legs, characterised in that the sensing electrodes

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comprise a first electrode configuration (sensor electrodes) for sensing vibrations either out of the plane of the tuning fork (24, 25, 26, 27) or in the plane of the tuning fork (7, 8, 9, 10, 11, 12) and a second electrode configuration (feedback electrodes) for sensing vibrations in the plane of the tuning fork (34, 35, 41, 42) or, respectively, out of the plane (9, 10, 11, 12) for regulating the in-plane or, respectively, out-of-plane driving of the tuning fork.

2. Electrode pattern according to Claim 1, characterised in that the drive electrodes are divided into a first electrode configuration (7-12) for generating a vibration in the plane of the tuning fork and a second electrode configuration (9-12) for compensating for unwanted vibration out of the plane.

3. Electrode pattern according to Claim 2, characterised in that both legs (2, 3) of the tuning fork are galvanically insulated with separated electrode configurations for driving and sensing.

4. Electrode pattern according to Claim 3, characterised in that the conductors to the electrodes on the base part (4) of the gyro are divided into a drive side and a sensing side by means of an intermediate earth plane (5).

5. Electrode pattern according to Claim 2, characterised in that the first electrode configuration (7-12) of the drive electrodes is attached to the four sides of the one leg (2) and extends from the base to a distance of 30-60% of the length of the leg, whilst the second electrode configuration (9-12) is divided into two and extends along the front and back of the leg essentially along its entire length.

6. Electrode pattern according to Claim 5, characterised in that the sensor electrodes (24, 25, 26, 27) are attached to the front and back of the second leg (3) on the part which is closest to the base.

7. Electrode pattern according to Claim 6, characterised in that the sensor electrodes (24, 25, 26, 27) extend from the base to a distance of 30-60% of the length of the leg.

8. Electrode pattern according to Claim 6, characterised in that the sensor electrodes (24, 25, 26, 27) also partly cover the base of the tuning fork.

9. Electrode pattern according to Claim 6, characterised in that the feedback electrodes (34, 35, 41, 42) are arranged furthest out on the leg on its four sides.

10. Electrode pattern according to Claim 9, characterised in that the feedback electrodes (34, 35, 41, 42) extend from the tip of the leg to the sensor electrodes (24, 25, 26, 27).

11. Electrode pattern according to Claim 4, characterised in that the conductors to the electrodes are arranged in such a manner that the number of output pads is minimised and is placed on one side of the base part (4) of the tuning fork.

12. Electrode pattern according to Claims 2, 5, 6, 7, 8, 9, 10, characterised in that the direction of drive vibration and the direction of sensor vibration change places, which means that the configurations 24-27 and 7-12 and, respectively, 34-35, 41-42 and 9-12 should be exchanged in the above patent claims.

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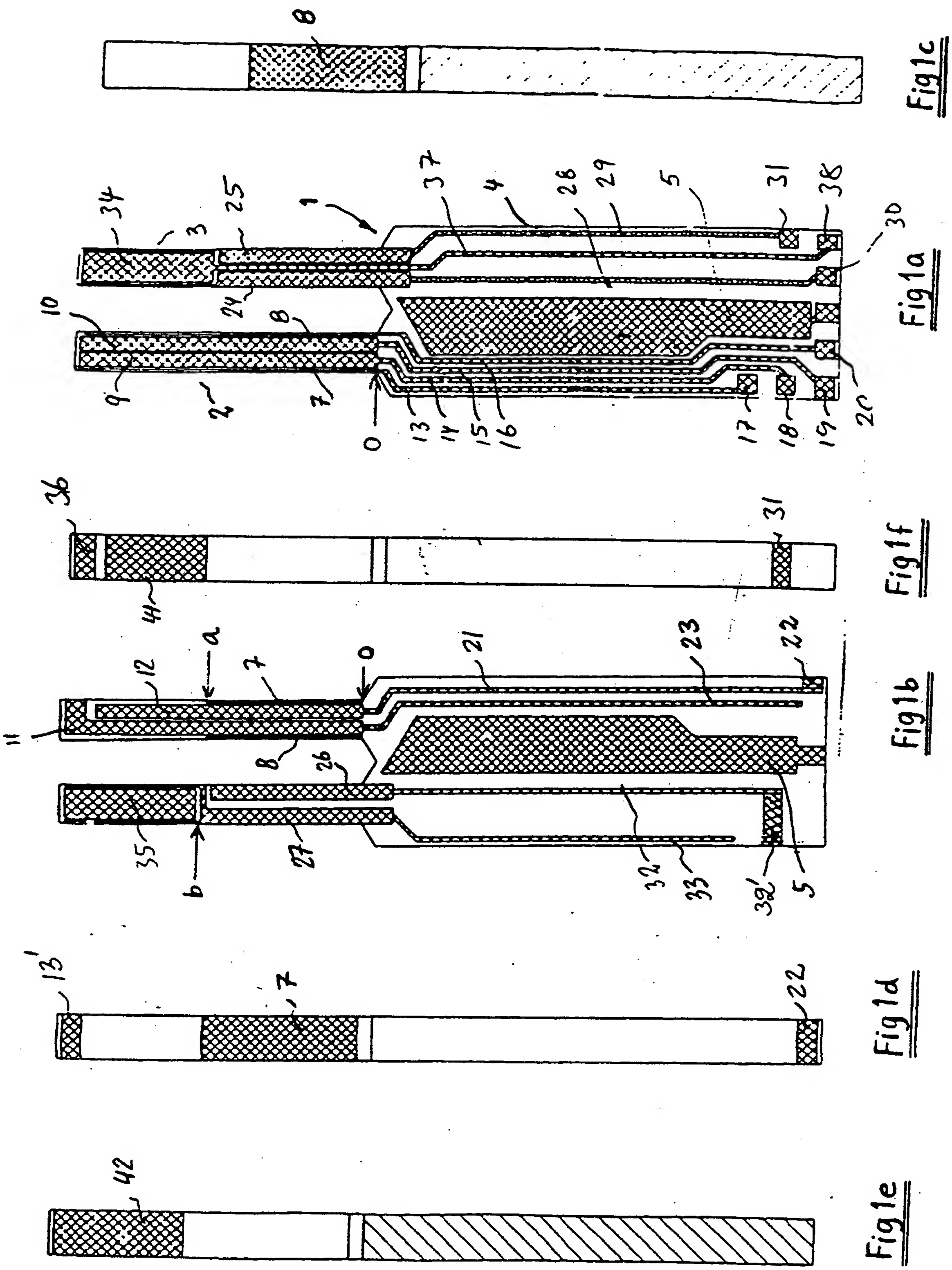


Fig1c

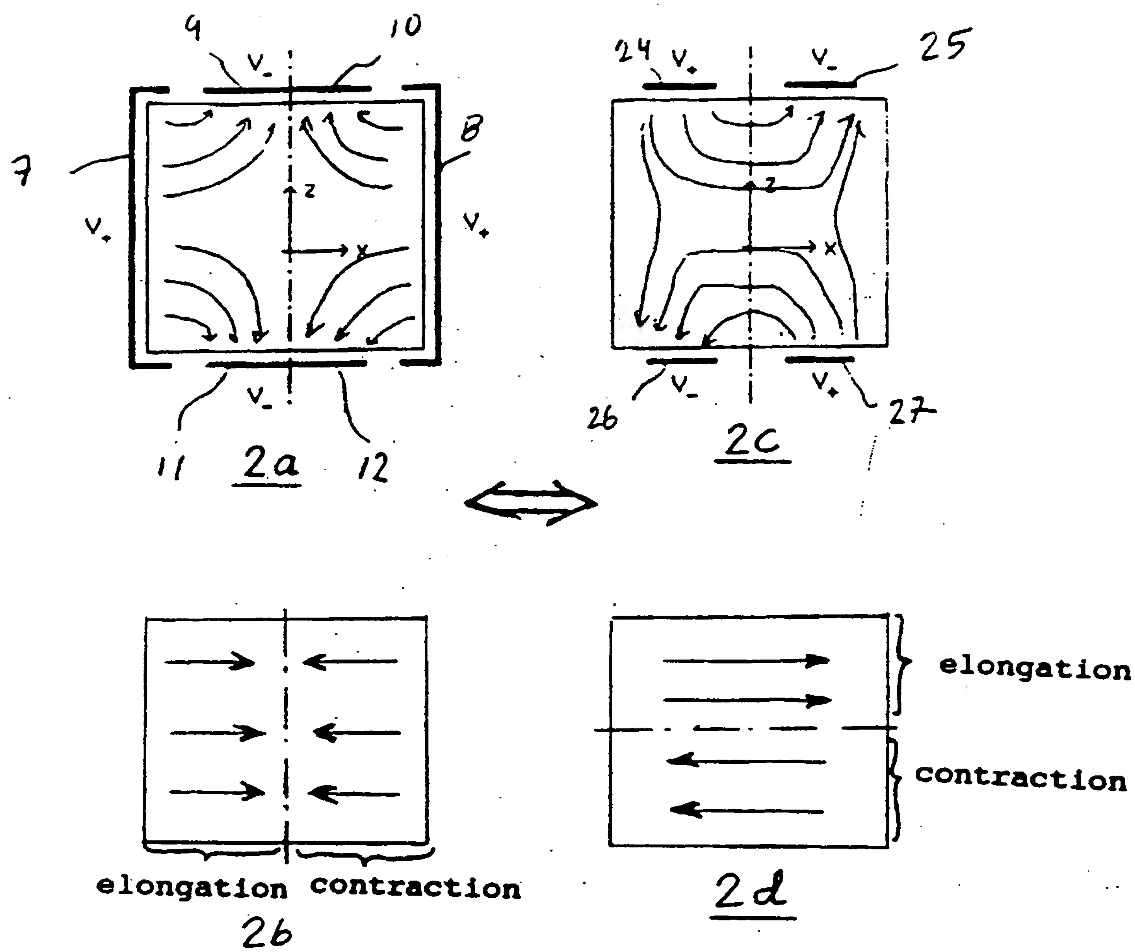
Fig1a

Fig1f

Fig1b

Fig1d

Fig1e



9
10
V-
7
8
V+
V+
z
x
V-
11
12
2a
24
25
V+
V-
z
x
V-
V+
26
27
2c
elongation
contraction
2b
elongation
contraction
2d

Fig.2

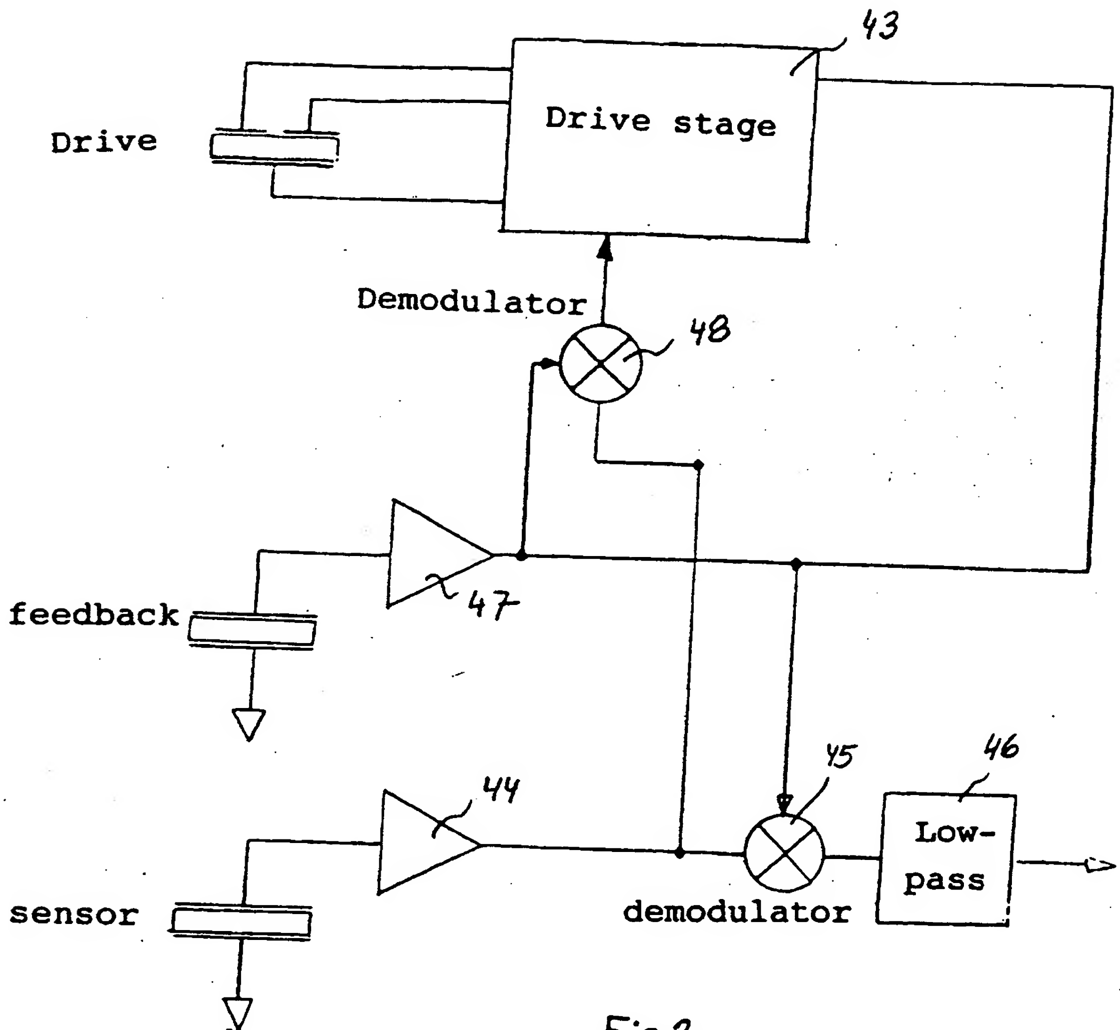

43
Drive
Drive stage
Demodulator
48
feedback
47
44
45
46
Low-
pass
sensor
demodulator

Fig.3

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EUROPEAN SEARCH REPORT

Application Number

EP 91 85 0325

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A,D	WO-A-9 010 196 (AB BOFORS) * page 4, last paragraph - page 5, paragraph 3 * * page 6, paragraph 3 - page 9, paragraph 2 * * page 10, last paragraph - page 11, paragraph 2; figures *	1-12	G01C19/56 G01P9/04
A	EP-A-0 161 049 (MATSUSHITA) * page 10, line 5 - page 11, line 27 * * page 13, line 13 - page 14, line 18 * * page 15, line 15 - line 26; figures 1,2 *	1,3,10	
A	EP-A-0 298 651 (THORN EMI) * column 3, line 29 - column 4, line 3; figures 1A-C,3 *	1,2	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			G01C G01P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	21 APRIL 1992	PFLUGFELDER G.F.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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